

SUSTAINABLE MANAGEMENT INITIATIVES FOR THE SOUTHERN AFRICAN HAKE FISHERIES OVER RECENT YEARS

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ABSTRACT

The predominantly trawl fishery for hake contributes about half the landed value of all of South Africa's commercial fisheries, and is approaching the largest contributor to Namibia's gross domestic product (GDP). Two hake species are taken by these fisheries: shallow-water hake *Merluccius capensis* Castelnau, 1861 and deep-water hake *Merluccius paradoxus* Franca, 1960. The present management framework separates the resources into three areas: Namibia and the South African West and South Coasts. Some 30 yrs ago, particularly as a result of rapidly increasing foreign fishing effort over the preceding decade, all of these hake stocks had been severely depleted. We address the question of how successfully sustainable utilization and resource recovery has been achieved since that time. Although there has indeed been some recovery—to a greater extent for the stocks off South Africa—the historical record indicates over-optimistic appraisals of likely recovery rates and sustainable yield levels over this period, and some of the reasons for this are discussed. Certain key assessment questions remain: why is recruitment variability estimated to be so low, natural mortality so high, and why do estimates of stock-recruitment steepness, survey selectivity-at-age and bias in swept-area survey estimates differ so greatly between the stocks? For the most part, total allowable catch (TAC) for these fisheries over the past decade have been set using Operational Management Procedures (OMPs), pre-set rules applied to pre-specified resource monitoring data, where the selection of the procedure to be used is based upon simulation testing to ensure adequate robustness to uncertainties in data and model-structure, in the spirit of a precautionary approach. We discuss the ability in practice of this approach to achieve the necessary adaptive framework for management and summarize planned future initiatives towards refining this OMP approach. These include changing from the present species-aggregated to separate procedures for *M. capensis* and *M. paradoxus*. This is necessitated particularly by an increasing longline component in the South African hake fishery, which focuses on *M. capensis* and takes mainly 6+ aged fish, compared to the mainly 3+ by the trawlers.

Three species of hake are present in the seas off southern Africa: the Benguela hake (*Merluccius polli* Cadenat, 1950), the shallow-water Cape hake (*Merluccius capensis* Castelnau, 1861) and the deep-water Cape hake (*Merluccius paradoxus* Franca, 1960). Figure 1 shows the distributions of these species. This paper will focus on Namibian and South African fisheries; the Benguela hake which occurs off Angola will not be considered further. Figure 1 also shows the management divisions for hake adopted by the International Commission for South East Atlantic Fisheries (ICSEAF), which played a role in the management of these hake fisheries over the period from 1972 until Namibian independence in 1990. ICSEAF separated the *M. capensis* and *M. paradoxus* resources into four stocks for management purposes: Divisions 1.3 + 1.4, 1.5, 1.6, and 2.1 + 2.2. More recently management units have been defined as the Namibian stock from the Kunene to the Orange river (considered equivalent to divisions 1.3 + 1.4 + 1.5), the South African West Coast stock from the Orange River to Cape Agulhas at 20°E (the previous Division 1.6), and the South African

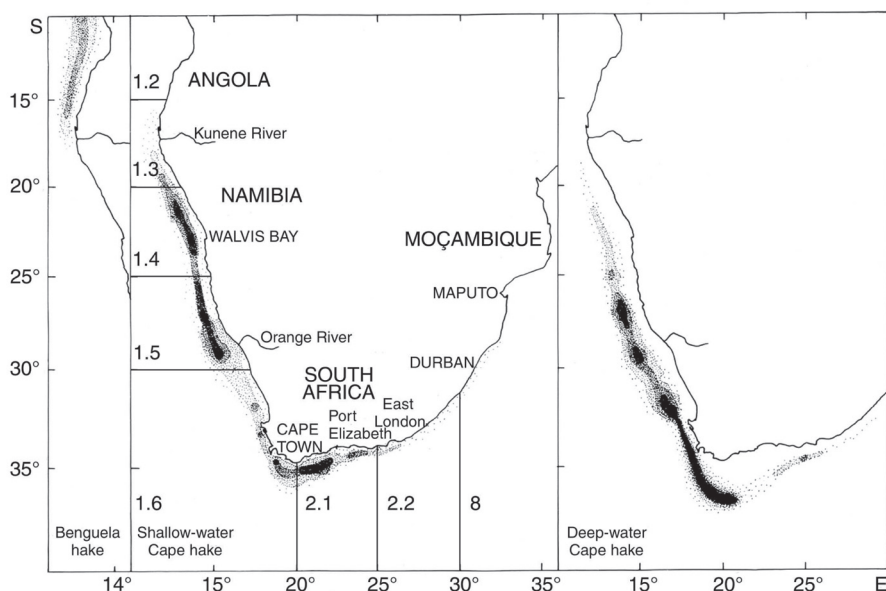


Figure 1. Management units and species distribution for southern African hake (from Payne, 1989, with permission).

South Coast stock east of Cape Agulhas (Divisions 2.1 + 2.2), except that the boundary between the stocks is taken to run southwest rather than due south of Cape Agulhas. Hereafter, for brevity, these will be referred to as the “Namibian,” “West Coast,” and “South Coast” hake stocks.

The biology of the Cape hake and history of the associated fisheries are described in Payne (1989), Payne and Punt (1995), and van der Westhuizen (2001). A key factor is that management treats the two species, *M. capensis* and *M. paradoxus*, as one. The reason is that these species are not distinguished in the records of commercial landings, although species-disaggregated information is available from research surveys. Historically the fishery has been conducted almost exclusively by bottom trawl, but over about the past decade longlining activities have increased, and (with handlining) account for almost 10% of the South African hake fishery landings at present.

Both shallow- and deep-water species show a trend of older (and larger) fish occurring at greater depths. Their distributions overlap, and there is considerable cannibalism and inter-species predation, particularly on fish of ages 0–2 yrs (Punt and Leslie, 1995). The trawl fishery takes place in the region of overlap, primarily in the 200–500 m depth range.

Both the South African and Namibian hake fisheries are of some economic importance. The 148,000 t South African hake catch in 1997 constituted about 80% by value of the country’s demersal fishery, whose wholesale value was about Rand 1.1 billion (2003 equivalent to some US\$70 million); the demersal fishery in turn accounted for almost half the value of all South Africa’s fisheries combined (Stuttaford, 1999). By 2001 the South African hake total allowable catch (TAC) had risen to 166,000 t. In Namibia, the hake fishery with a 2001 TAC of 200,000 t is near to becoming the largest single contributor (over 10%) to the country’s GDP (MFMR, 1999).

Figure 2 shows the catch histories in these fisheries as they appeared in 1972. (The hake fishery in South Africa actually began in 1917, but catches prior to the 1950s were relatively small.) From the mid-1960s, these fisheries exhibit a pattern of rapidly growing effort by foreign fleets, particularly off Namibia (note the different scales for the catch plots in Fig. 2). Figure 2 also shows the catch per unit effort (CPUE) trends as they appeared in these fisheries at that time some 30 yrs ago. These trends all reveal a common pattern of a steep decline. It was primarily concern over this combination of rapidly rising catches and declining abundance indices that led to the formation of ICSEAF in 1972.

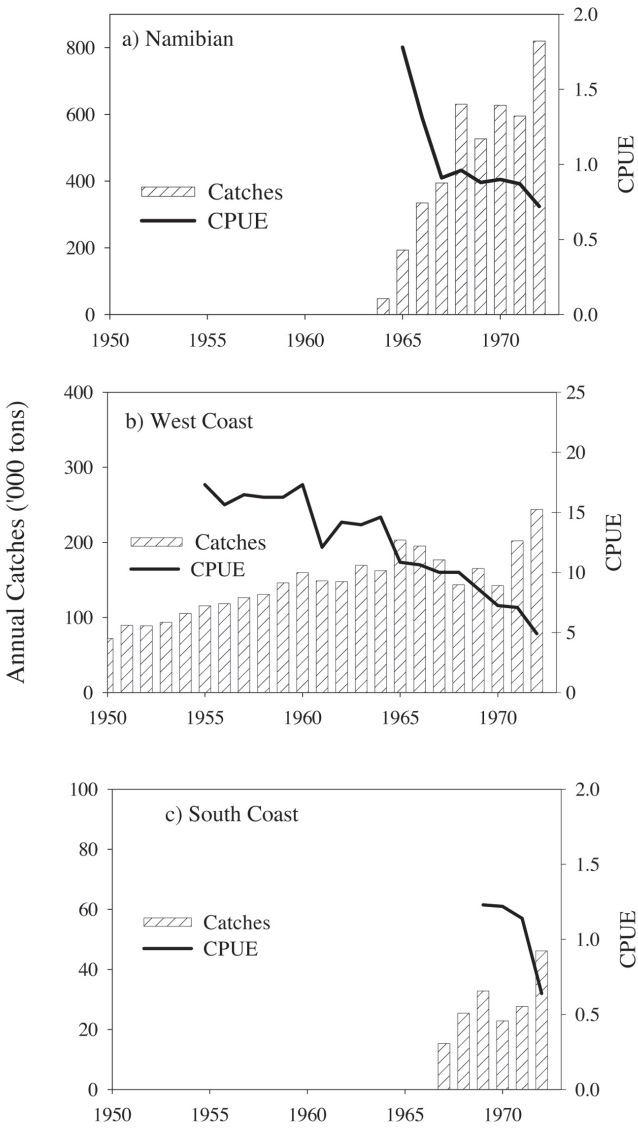


Figure 2. Annual catches and CPUE data up to 1972 for (A) Namibian, (B) West Coast, and (C) South Coast hake stocks. Note that the CPUE units used at the time were not comparable across the three stocks.

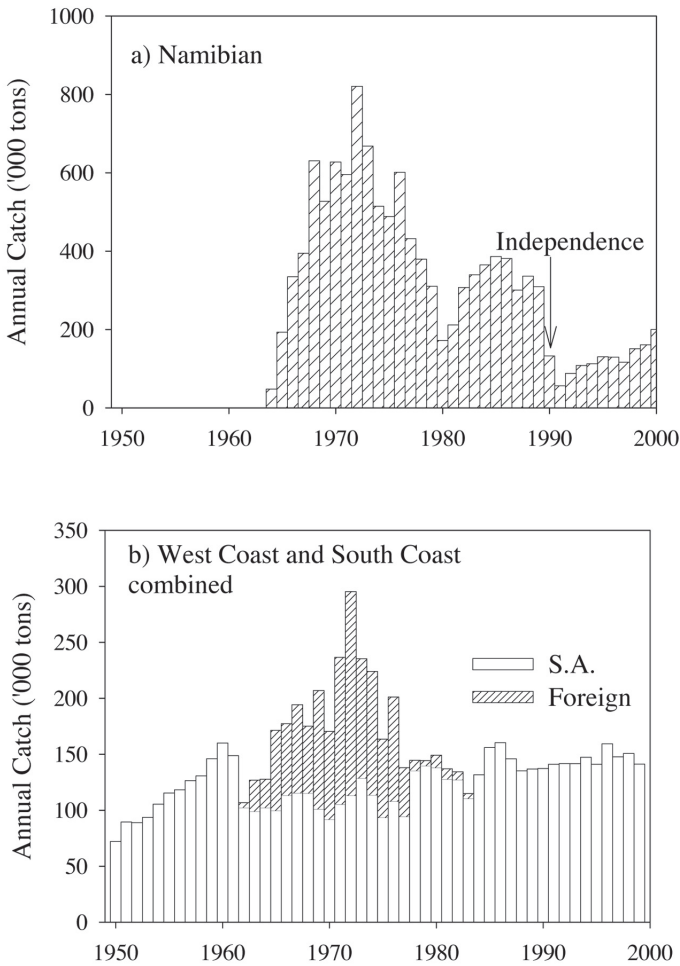


Figure 3. Catch time series for (A) Namibian and (B) South African (West and South Coasts combined) hake.

This paper addresses four topics: (1) the success of sustainable utilization achieved and resource recovery facilitated by the management initiatives of the past three decades; (2) the assessment analyses used to address this topic, which give rise to some key outstanding questions; (3) past, recent, and current management practices (based primarily on the Operational Management Procedure [OMP] approach); and (4) initiatives for the immediate future along these lines.

RESOURCE RECOVERIES?

Figure 3 extends the catch series of Figure 2 to cover the last 30 yrs. Namibian annual hake catches declined appreciably from 800,000–200,000 t until 1980. Under ICSEAF these levels rose again to some 400,000 t during the 1980s (though there is concern about the accuracy of some of the catch reporting over this period). These catches remained almost exclusively by foreign fleets over that period. When man-

agement passed into Namibian hands with independence in 1990, catches were substantially reduced, to little more than 50,000 t, but have subsequently risen to nearly 200,000 t, fished by what is now a locally-based industry.

The picture for South Africa is a little different. Catches there also fell substantially over the late 1970s, from a high of about 300 to some 150,000 t. Decreased foreign activity accounted for most of this drop, however, and after South Africa declared its Exclusive Economic Zone (EEZ) in 1977 and took over control of the fishery from IC-SEAF, foreign catches were quickly phased out. In terms of total landings then, aside from a small drop from the early 1960s to mid-1970s, the domestic hake fishery's catches have remained relatively constant, with a slightly increasing trend over the last decade.

Resource abundance trends are estimated by use of age-structured production models (ASPMs) (e.g., Butterworth and Geromont, 2001; Rademeyer and Butterworth, 2001). These models are fit to abundance indices and catch-at-age data from both the commercial fishery and from research surveys. For Namibia pre-independence and for South Africa prior to EEZ declaration, the nominal CPUE-based abundance indices were adjusted only by somewhat crudely estimated vessel power factors. For more recent years for which detailed data are available, more sophisticated general linear model (GLM) techniques have been used to standardize these series for vessel and spatio-temporal fishing distribution effects (e.g., Glazer and Butterworth, 2002). Research survey abundance estimates are based on systematic swept-area surveys. These provide estimates in absolute terms, but they are treated as relative indices in the maximum likelihood population model-fitting process.

Results of ASPM fits to the most recent data for the Namibian, West Coast, and South Coast resources are shown in Figures 4–6 respectively. The last of these results is for the *M. capensis* component of that resource only, for reasons to be discussed later (see the subsection on OMP revision for this resource). The first two fits are deterministic (i.e., no fluctuations about the assumed Beverton-Holt stock-recruitment function), but the third makes allowance for such fluctuations. These plots give the estimated spawning biomass trajectory, shown as a proportion of the corresponding average pre-exploitation level (B^{sp}/K), together with comparisons of the primary abundance indices used in fitting the model and the corresponding model predictions. Note that the latter take account of estimated age-specific selectivity functions, which are index-dependent and sometimes also change over time.

These results suggest that decline in Namibian hake abundance continued until 1990, but that the further TAC reductions in the 1990s have allowed for a slight recovery (Fig. 4A). For the West Coast stock, a steady though slow increase since catches were reduced in the mid-1970s is indicated, with abundance now at a level corresponding to MSY (MSYL; Fig. 5A). The *M. capensis* stock on the South Coast appears to have rebounded rapidly after the mid-1970s catch reductions, and has been roughly steady for the last two decades at well above its MSYL (Fig. 6A; the reason for the surprisingly low estimated MSYL in this case is discussed later). The fits to the abundance indices appear reasonable, though indicate relatively high levels of residual variance, particularly for more recent years.

A RETROSPECTIVE ANALYSIS.—Although the results above indicate that some resource recovery has been achieved over the last three decades, how did the situation appear as this period progressed?

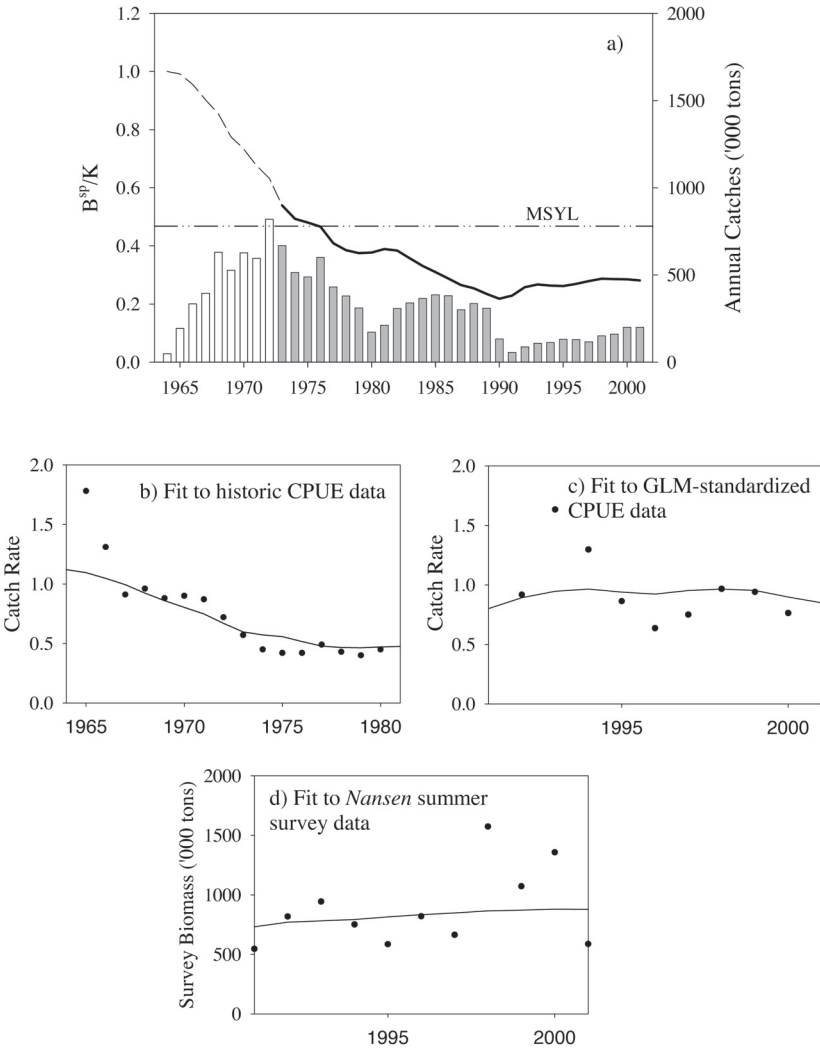


Figure 4. Deterministic ASPM assessment (A) and fits to abundance indices (B–D) for the Namibian hake resource. Resource abundance, both here and in the figures following, is expressed in terms of spawning biomass as a proportion of the pre-exploitation equilibrium level (B^{sp}/K), with the pre- and post-1972 periods distinguished. In this and following figures, MSYL refers to the level of abundance at which MSY is achieved; for the spawning biomass trajectories, the pre- and post-1972 periods are distinguished by dashed and full lines respectively.

Figure 7 compares the results of the most recent deterministic ASPM assessments for Namibia and the West Coast (as in Figs. 4A and 5A, respectively) with those carried out in earlier years. The results are not exactly comparable, as the earlier assessments were carried out by means of an age-aggregated production model (the dynamic Schaefer model):

$$B_{y+1} = B_y + rB_y(1 - B_y/K) - C_y \tag{1}$$

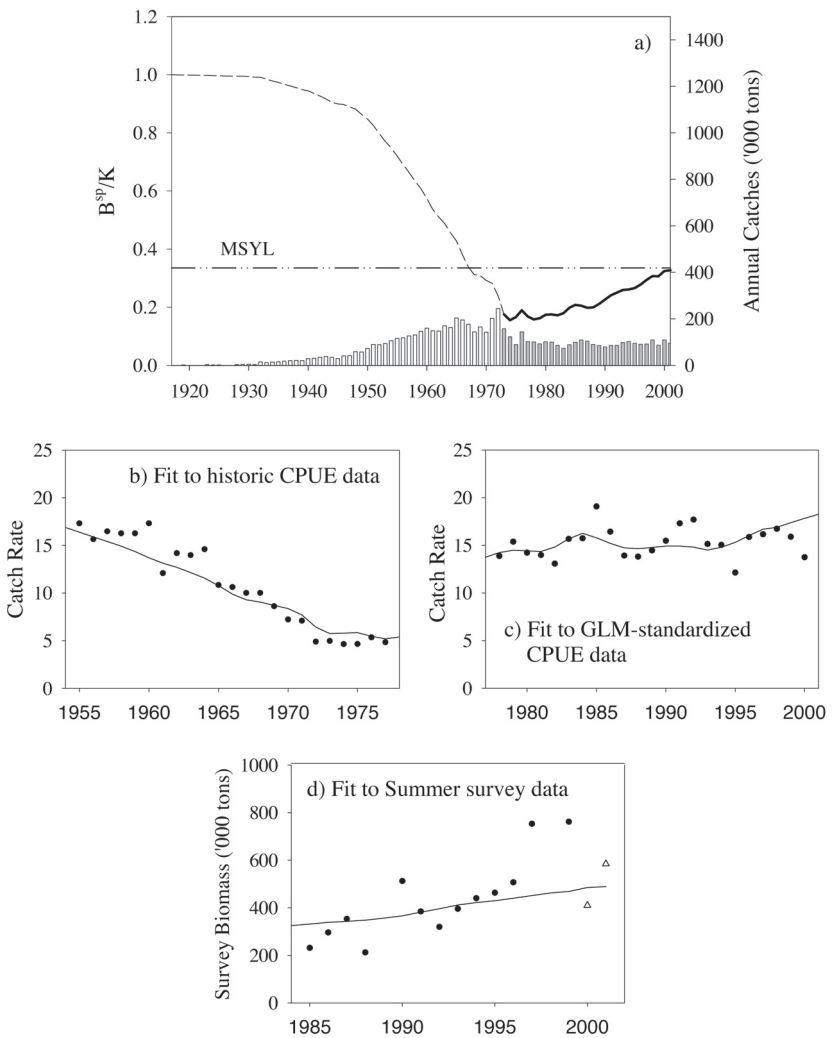


Figure 5. Deterministic ASPM assessment (A) and fits to abundance indices (B–D) for the West Coast hake resource. The last two survey points in (D) were obtained from a different research vessel (the R/V NANSEN rather than the R/V AFRICANA), and have been adjusted in this plot for the relative biases for the two vessels as estimated in the model-fitting process.

where B_y is the biomass in year y , C_y the catch that year, and r and K estimable model parameters (MSYL for this model is at $B/K = 0.5$). Furthermore, the results shown here for Namibia combine Divisions 1.3 + 1.4, and 1.5, though these were assessed separately prior to 1990. These Figure 7 plots also show biomass projections under the catches that were subsequently taken, and furthermore, the progression of MSY estimates corresponding to these assessments. Even admitting the lack of precise comparability over time because of the changed assessment method, these plots evidence a clear retrospective pattern. As time progressed, estimates of the extent and rate of recovery declined, and estimated sustainable yield levels also dropped below previous expectations. The differences are especially large in the Namibian case. What are the reasons underlying these patterns?

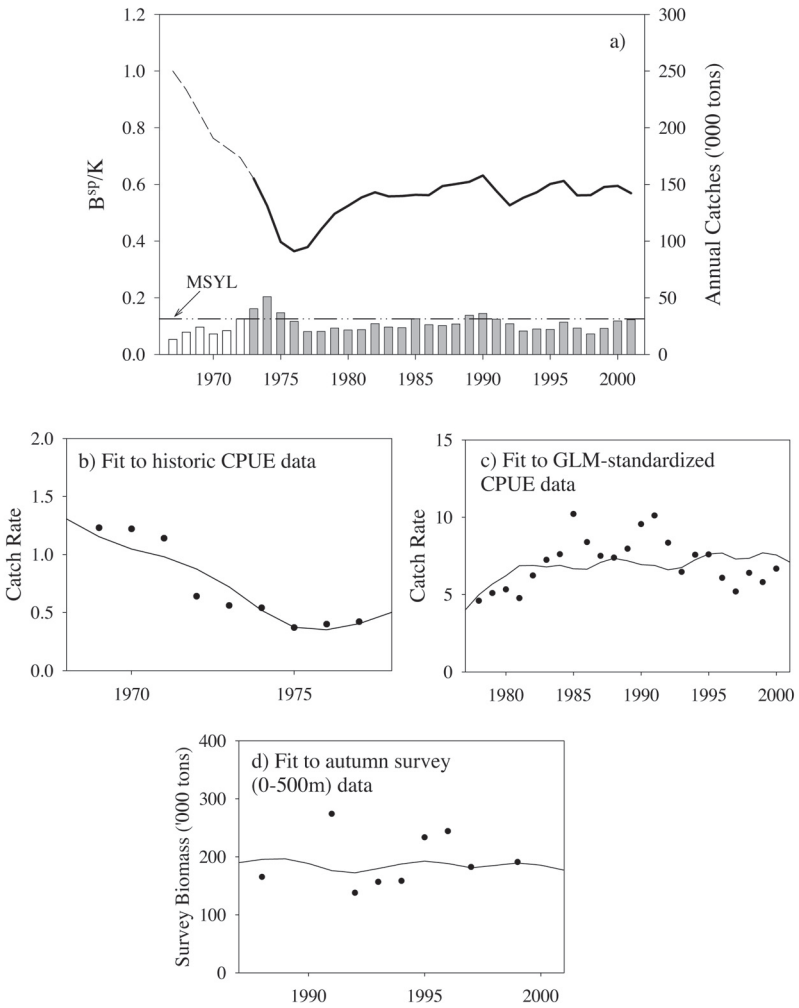


Figure 6. ASPM assessment with recruit variation (A) and fits to abundance indices (B–D) for the South Coast *M. capensis* resource.

Figure 8 compares the current deterministic ASPM estimate of the expected trend of the CPUE index of abundance with the CPUE data provided to ICSEAF for Namibian hake. These data show an upturn in the 1980s, and this is the primary reason for the optimistic assessments during that period as shown in Figure 7A, in line with which ICSEAF allowed catches to rise during this period (see Fig. 3A). However, these 1980s CPUE data are now regarded with skepticism. It is now known that there was misreporting of catches over this period, and furthermore, the reported rising CPUE hardly seems consistent with the fact that towards the end of the 1980s, some of the foreign fishing vessels were leaving Namibian waters to fish elsewhere. Current assessments, as in Figure 4A, disregard these post-1980 ICSEAF CPUE data, with the consequent major impact on estimated resource trends and productivity levels that is evident in Figure 7A.

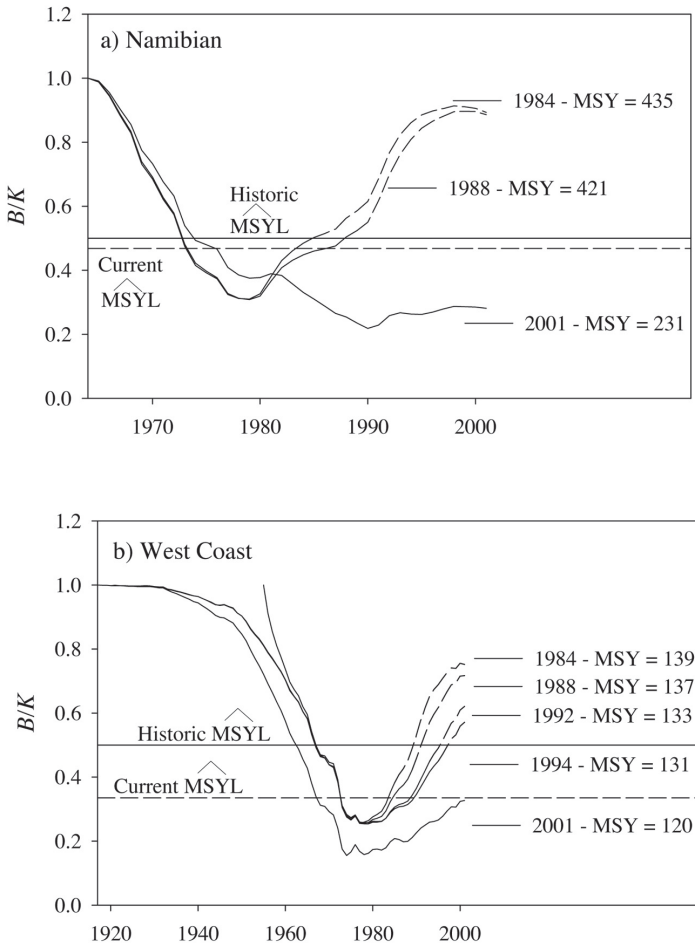


Figure 7. Current and historic assessments (with projections under catches subsequently taken, which are shown as dashed lines) for (A) Namibian and (B) West Coast hake. Estimated MSY values are in thousands of tons. The current assessments are based upon ASPMs, whereas the historic ones utilized the age-aggregated Schaefer dynamic production model.

The reason underlying the retrospective pattern in Figure 7B for the West Coast is rather different. Over the late 1980s and early 1990s, CPUE did not increase as rapidly as predicted by the dynamic Schaefer model (equation 1) used for assessments at the time, resulting in increasingly less optimistic appraisals of the resource. Before 1995, only coarsely estimated power factors for vessel classes had been used to adjust the nominal CPUE. At that time, a thorough GLM-based standardization exercise was undertaken, with results as shown in Figure 9. The nominal upward trend in CPUE of 3.4% p.a. remained positive at 1.2% after accounting for the change in the fleet towards more powerful vessels. However, when allowance was also made for bycatch, depth, and latitude factors, the evidence for any increasing trend disappeared (Fig. 9C). This further adjustment was a consequence both of movement of the fleet towards deeper water where catch rates were higher, and also of a shift in the hake distribution towards deeper water. Even after refining the GLM to attempt

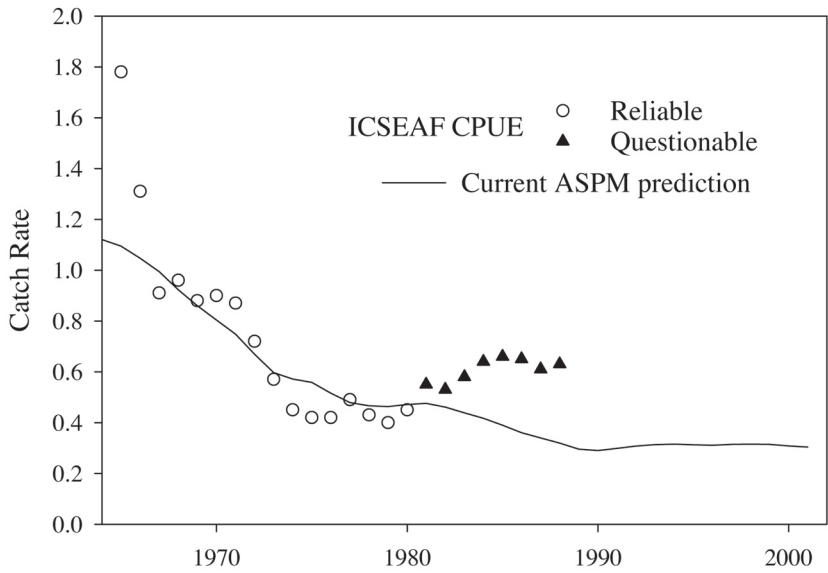


Figure 8. ICSEAF CPUE data for the Namibian hake, showing the questionable period.

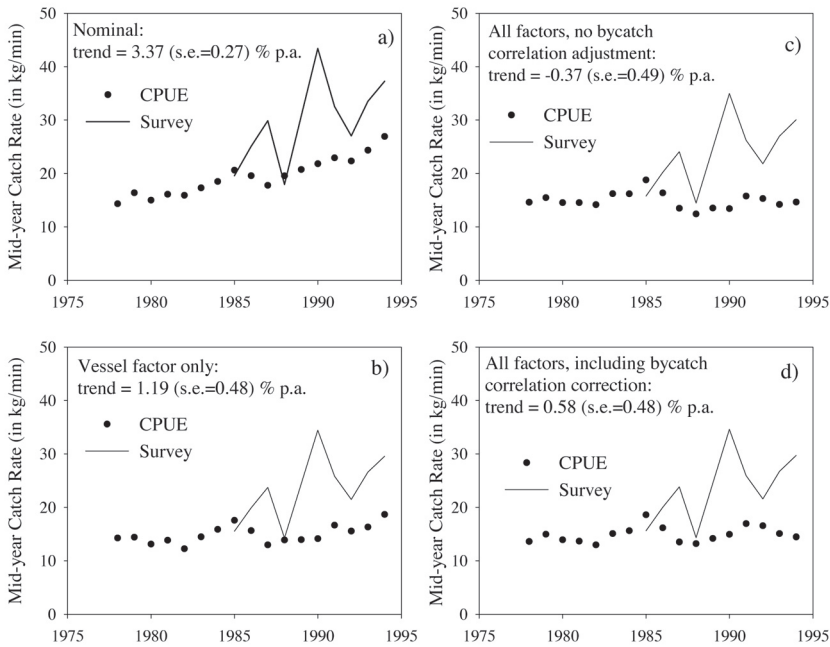


Figure 9. Comparison of survey and GLM standardized CPUE trends for West Coast hake.

to take account of positive correlations in hake and bycatch CPUE measures, such upward trend as remained was rather small (only 0.6% p.a. – see Fig. 9D; Glazer and Butterworth, 2002).

Straightforward substitution of the CPUE series of Figure 9D into the assessment model in use at the time (1995) would have resulted in a large TAC cut, a prospect not well received by the industry which argued strongly that a lack of any catch rate increase over the previous two decades (indicating no recovery at all of the resource) was contrary to their experience. They furthermore pointed to the upward trend in the abundance estimates from research surveys (5.8% p.a.; s.e. 2.6%), though large variability meant that this trend estimate was not statistically inconsistent with that for the standardized CPUE data.

In off-the-record discussions with industry, the likely real explanation for these results became apparent. The first conservation measure taken by ICSEAF in 1975 had been to increase the minimum mesh size to 110 mm for the hake trawl fishery. However, this had rendered catch rates uneconomical, so that vessels had (illegally) inserted liners in their nets. As catch rates later improved as the stock recovered, use of these liners was phased out. Thus recorded catch rates did not increase as fast as abundance because CPUE was indexing an increasingly smaller proportion of the biomass as time progressed (unlike the research surveys). The length distributions of the hake catches provide independent confirmation of this, with a decreasing proportion of 1- and 2-yr old fish in the catch as the 1980s progressed into the early 1990s.

Current assessments therefore make allowance for a decrease in selectivity for younger fish over the period that liners were phased out (see Fig. 10). This is why the ASPM model predicts a less increasing trend for CPUE than for research survey results over the last two decades (see Figs. 5C,D respectively), and also why (despite only a small increasing trend in the standardized CPUE of Fig. 9D) the West Coast stock is considered to have made a reasonable recovery over the last 30 yrs.

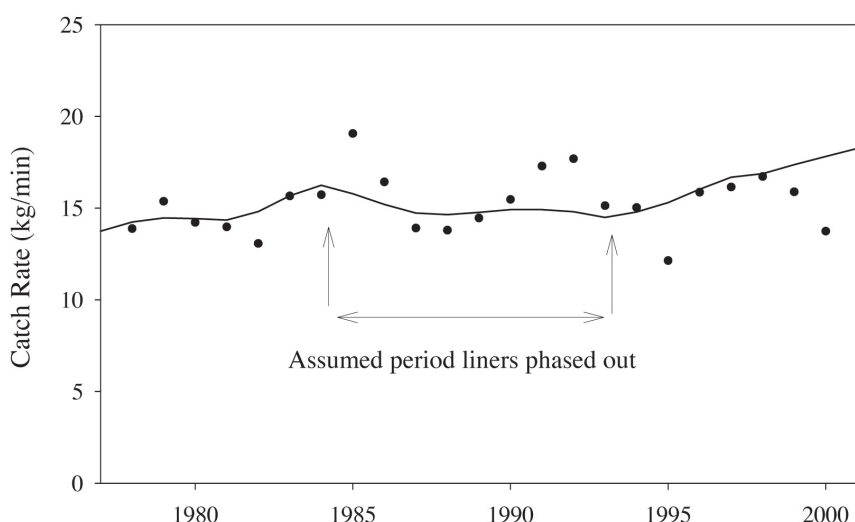


Figure 10. Time series of GLM-standardized CPUE (data points) for West Coast hake, showing period during which liners are assumed to have been phased out. The line shows the values predicted by the deterministic ASPM assessment.

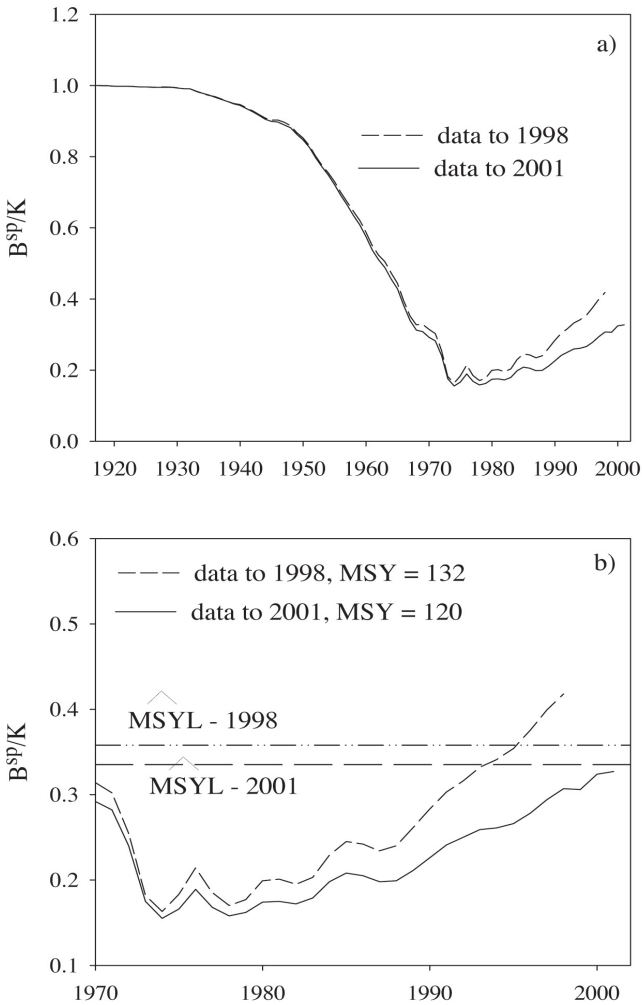


Figure 11. Retrospective deterministic ASPM for West Coast hake. Estimated MSY values are in thousands of tons.

Even so, if the current deterministic ASPM methodology is applied while omitting data for the last 3 yrs, the retrospective pattern remains (Fig. 11). The reason for this trend in estimates is that even with liners now presumably not in use for some time, CPUE has not shown a recent increasing trend as the model predicts (see Fig. 10), a matter which is of some concern.

FURTHER ASSESSMENT RESULTS.—The deterministic ASPM assumes annual recruitment R_y to be a deterministic function of spawning biomass B_y^{sp} :

$$R_y = R(B_y^{sp}) \tag{2}$$

where the function R here is chosen to have a Beverton-Holt form. This model for recruitment can be extended to allow for annual fluctuations about this relationship by modification to:

$$R_y = R(B_y^{sp})e^{\varepsilon_y} \quad \varepsilon_y \sim N(0, \sigma_R^2) \quad (3)$$

where residuals are assumed to be log-normally distributed with the ε_y s becoming estimable parameters (made possible by the availability of catch-at-age, as well as relative abundance data, though only for the cohorts for which the available catch-at-age data give information) for the model fitting process (see, e.g., Geromont and Butterworth, 2000). The negative log likelihood minimized in the fitting procedure has a penalty term:

$$\sum_y \left[\ln \sigma_R + \varepsilon_y^2 / (2\sigma_R^2) \right] \quad (4)$$

added to take account of the log-normality distributional assumption in the spirit of a Bayesian random effects model approach. In principle, this extension allows movement away from the assumption of the deterministic assessments that resources were at their unexploited equilibrium abundances (K) when catches commenced; however, this possibility has not been investigated to date as catch-at-age data become available only some time after such commencements.

Figure 12 shows the consequences of admitting such recruitment fluctuations in the Namibian and West Coast hake ASPM assessments. The log residual standard deviation σ_R is fixed at 0.25 in both cases; this is discussed further below. The introduction of these residuals makes little difference to the results for the West Coast, but leads to a rather more positive appraisal for the Namibian stock, essentially because catch-at-age data for the 1980s suggest that some strong cohorts entered the fishery in the middle of that decade.

Bootstrap estimates of precision for these ASPMs incorporating recruitment fluctuation are shown in Figure 13. A clear difference between the Namibian and West Coast stocks is that MSY is determined much more precisely for the latter. The reason for this is the increasing trend in recent abundance indices in the latter but not the former case (see Figs. 4 and 5, respectively). This means that the Namibian resource still reflects a "one way trip" situation (Hilborn, 1979), for which precise estimation of productivity-related parameters is problematic. For the same reason, the current status of the Namibian resource (with a wide 90% confidence interval from 16%–69% for B^{sp}/K) is rather less certain than that of West Coast hake, making it impossible to rule out the chance that there has been some net decline in the Namibian resource over the last two decades.

OUTSTANDING KEY ASSESSMENT QUESTIONS

The assessment results presented above cannot be viewed with complete confidence because of some important questions, which arise from other features of these analyses.

RECRUITMENT VARIABILITY.—A somewhat unsatisfactory aspect of the maximum-likelihood-based assessment methodology applied to incorporate recruitment fluctuations (refer specifically to equations 3–4 and the associated text), is that the value of σ_R cannot be estimated from the data but must be independently specified. This is problematic particularly in cases such as that for Namibian hake (see Fig.

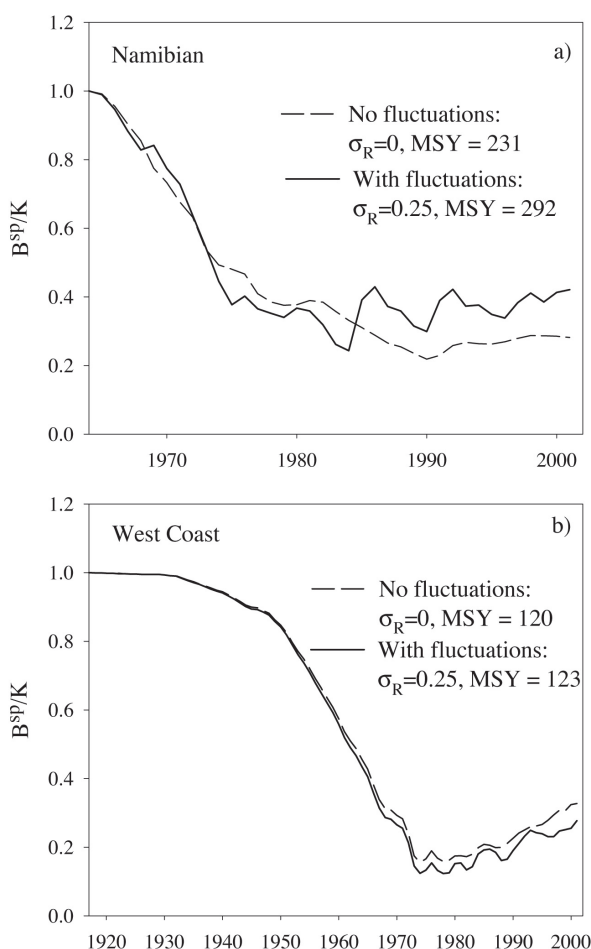


Figure 12. Effect of allowing stock-recruitment fluctuations in ASPM assessments for (A) Namibian and (B) West Coast hake.

12A) where estimates of stock and productivity are strongly dependent on the value chosen for what we term " σ_R (input)."

A corresponding " σ_R (output)" value can be computed in each case from the maximum likelihood estimates for the recruitment residuals. Figure 14 shows the relationship between the σ_R (output) and σ_R (input) values for the three stocks considered. [Note that similarity of the two values is not an argument to indicate a more appropriate choice of σ_R (input), as the penalized likelihood formulation used will always yield a maximum for the deterministic limit of $\sigma_R \rightarrow 0$. One would need to adopt fully Bayesian methodology, together with a prior for σ_R (input), to deal properly with this difficulty.] In the interests of inter-stock consistency, a common baseline value of σ_R (input) = 0.25 was used for the ASPM assessment results reported above. A higher value could be argued for the Namibian stock, but this would have led to a yet more positive appraisal of current resource status, the reliability of which depends crucially on catch-at-age data for the 1980s whose sources are not well documented.

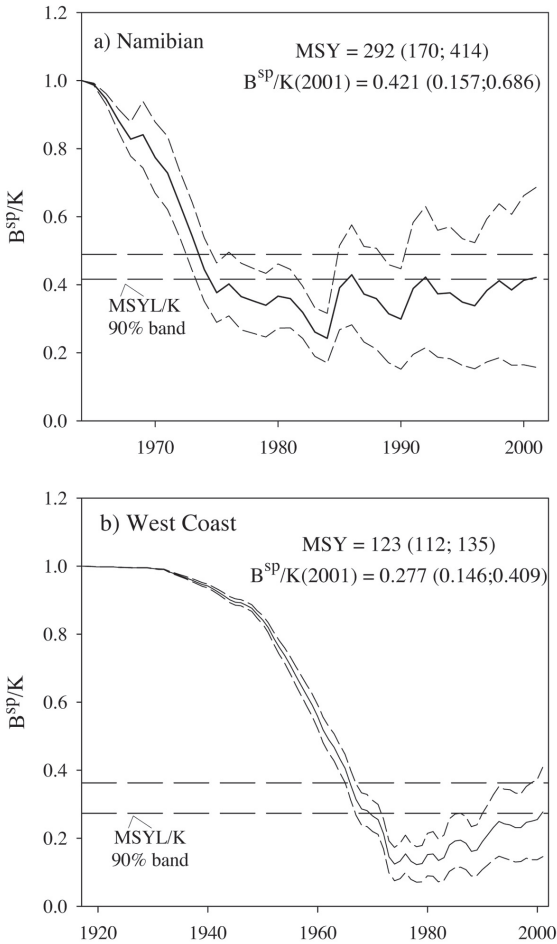


Figure 13. ASPM assessment (recruitment fluctuations included) with bootstrap 90% confidence intervals for (A) Namibian and (B) West Coast hake.

The intriguing feature of these plots is that for the South African stocks, whatever the value of σ_r (input) specified, σ_r (output) does not exceed 0.2. The results for the Namibian resource show a similar feature, though the asymptotic value does exceed 0.4. The low level of recruitment variability that this indicates for the South African stocks in particular is pushing the edge of the credible range. Teleosts generally show much greater levels of recruitment fluctuations (e.g., Beddington and Cooke [1983] list 26 other gadoids for only nine of which is $\sigma_r < 0.3$).

It could be that recruitment fluctuations are moderated by the heavy degree of cannibalism and inter-species predation on younger *M. capensis* and *M. paradoxus* [note that as fish younger than 2 yrs of age are hardly captured either in surveys or commercially, the assessment estimates of recruitment really refer to the proportion of recruits that survive their first 2 yrs of life]. Furthermore, since recruitment for two species are combined in the assessment, lesser net fluctuations would be expected unless there is positive recruitment correlation between the species. However, it

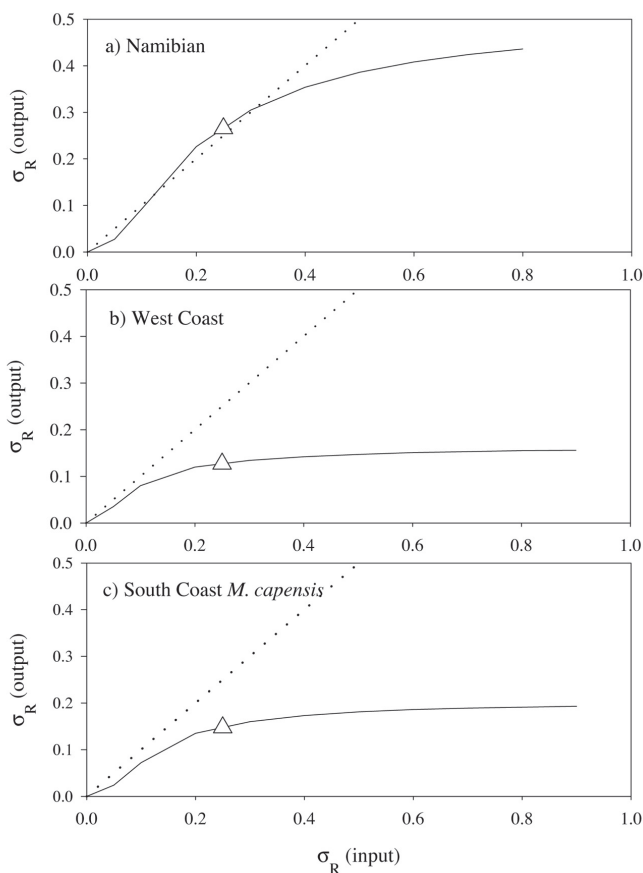


Figure 14. σ_R (input) vs σ_R (output) for (A) Namibian and (B) West Coast hake, and (C) South Coast *M. capensis*. Δ shows the assessment assumption. The dotted line reflects σ_R (output) equal to σ_R (input).

might also be that there is bias in hake ageing, which would confound the detection of stronger and weaker cohorts.

NATURAL MORTALITY.—Figure 15 shows the estimates of natural mortality M for each of the three stocks obtained when fitting the ASPM (with recruitment fluctuations). In the case of the West Coast, there is sufficient information (for ages above two) to move beyond the assumption that M is independent of age a , and a functional form:

$$M_a = \alpha + \beta/a \quad (5)$$

has been assumed for the estimation.

What is of concern is how high these estimates are. Values in excess of 0.5 yr^{-1} for mature hake (ages of four and above), which are little affected by cannibalism or predation by the other hake species, seem unrealistically large.

Postulating decreasing selectivity-at-age for the older fish (either as a result of greater net avoidance capabilities, or movement towards deeper waters than covered

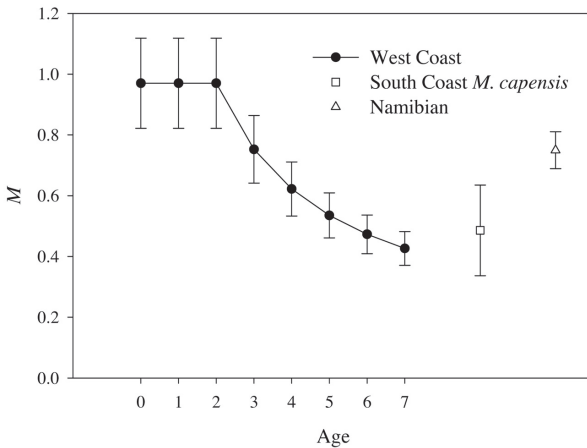


Figure 15. Estimates of natural mortality M for assessments with stock-recruitment fluctuations, shown together with bootstrap-based 90% confidence intervals. An age-dependent form for M is used only for the West Coast.

by fishing operations and surveys) would seem to have the potential to secure compensatory reductions in these natural mortality values towards more realistic levels. However, maximum likelihood estimation supports this only to a limited extent (if at all), as difficulties then arise for models in fitting the historic decline in CPUE.

Essentially the high M estimates arise because ageing (of both commercial and research survey samples) suggests the presence of only very few hake of ages seven and above. Therefore, considerations related to natural mortality give rise to questions about possible bias in ageing, as did concerns about estimates of the extent of recruitment variability.

STEEPNESS.—Natural mortality aside, the parameter upon which productivity of a stock (as a proportion of its average pre-exploitation biomass) most depends is the stock-recruitment curve steepness h . Figure 16 shows the stock-recruitment relationships estimated by the ASPMs which include recruitment fluctuations. These plots also show replacement lines, and demonstrate the definition of h (Mace and Doonan, 1988) as the proportion of the average pre-exploitation recruitment level to be expected when spawning biomass falls to 20% of its average unexploited value (K^{sp}). The sustainable yield capability of the stock is roughly indicated by the difference between the stock-recruitment curve and the replacement line, so that lower h values mean lesser stock productivity.

The surprising aspect of these results is the marked difference in the h estimates for the three stocks. This is not simply a chance outcome for imprecise estimates: the likelihood profiles for h in Figure 17 show that the differences are statistically significant. While the estimated value of $h = 0.54$ for the West Coast is only slightly on the low side of what is typical for similar fish stocks [Myers et al. (1999) report a median estimate for gadoids of 0.79 with a lower 20 percentile of 0.67 and upper 20 percentile of 0.87], the best estimate for South Coast *M. capensis* of $h = 1.0$ is unrealistically high, and is the reason for the low estimated MSYL shown in Figure 6 for this resource. At the other extreme, an $h = 0.28$ estimate for Namibian hake is extremely low (lower than any of the estimates for gadoids reported in Table 1 of Myers et al. [1999] which raises suspicions of possible bias in the assessment). Speculative reasons for poorer estimated hake productivity off Namibia compared to South Africa

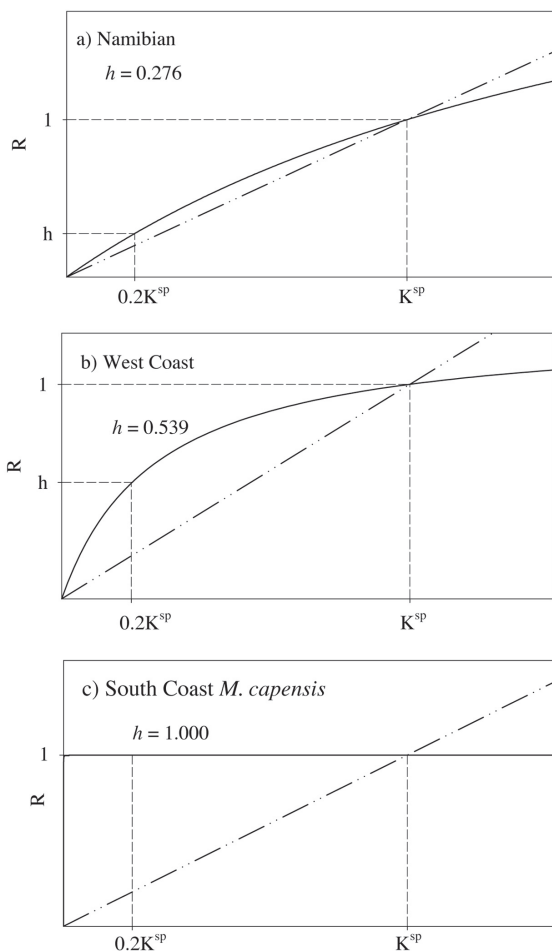


Figure 16. Estimated stock-recruitment relationships, characterized by steepness h , for (A) Namibian and (B) West Coast hake, and (C) South Coast *M. capensis*. Recruitment R is shown relative to its pre-exploitation equilibrium level. The straight lines through the origin are replacement lines, for which annual numbers of recruits would exactly balance the number of deaths in the absence of exploitation.

are the greater variability of the environment off Namibia (Shannon et al., 1992), and a possible ecosystem change related to the major reduction in the 1970s of the previously large sardine [*Sardinops sagax* (Jenyns, 1842)] resource off Namibia, which has remained at low levels since (Boyer et al., 2001).

SELECTIVITY FUNCTIONS.—The ASPM implemented also allows for estimation of age-specific selectivity functions of logistic shape, with a possible decrease at larger ages, for both the commercial fishery and the research surveys (conducted by the R/V NANSEN in Namibia, and for the most part by the R/V AFRICANA in South Africa). The results of this for the current selectivities are shown in Figure 18. This estimation is made possible through the availability of catch-at-age data for both commercial and research catches; the ASPM achieves reasonable fits to these data, as illustrated for the West Coast (Fig. 19).

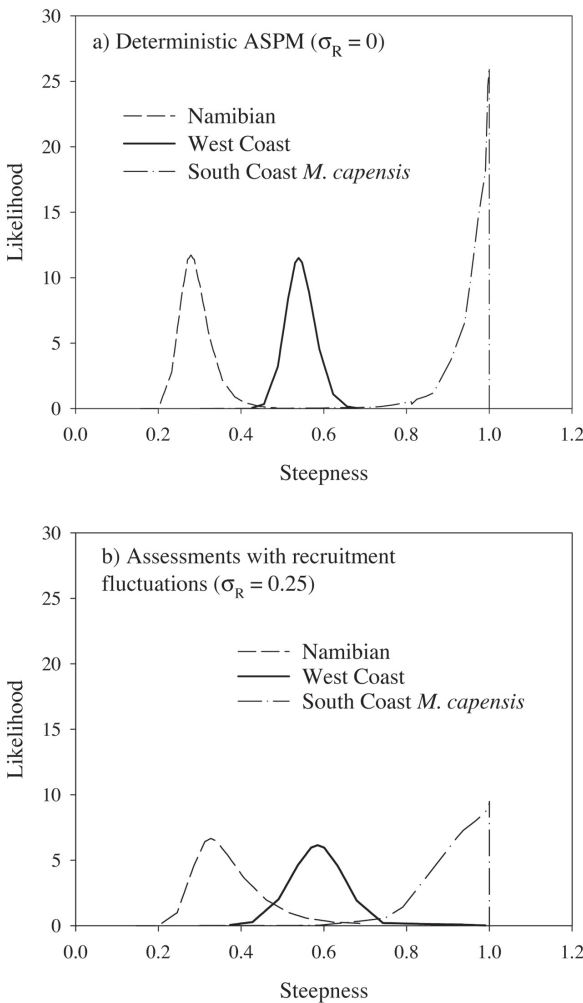


Figure 17. Likelihood profiles for steepness h for (A) deterministic ASPMs and (B) assessments with stock-recruitment fluctuations. The curves have been scaled so that area under each is the same.

The surprising feature of the plots in Figure 18 is how different some of these estimated relationships are. The reduced selectivity for younger hake in the present commercial fishery off Namibia is understandable because of post-independence regulations there that restrict fishing to deeper than 200 m to protect juvenile hake. Similarly the low commercial selectivity for younger shallow-water *M. capensis* on the South Coast is attributable to the fact that the catch-at-age data are from the offshore trawl fleet, but that does not explain the similar under-representation of younger *M. capensis* in the research survey catches, as these surveys are intended to cover the full distributional range of the resource. This under-representation raises the question of whether the *M. capensis* on the South Coast are indeed a separate stock to those on the West Coast.

SURVEY BIAS.—Although hake abundance estimates from research surveys are available in absolute terms, based upon swept-area methodology, they are treated

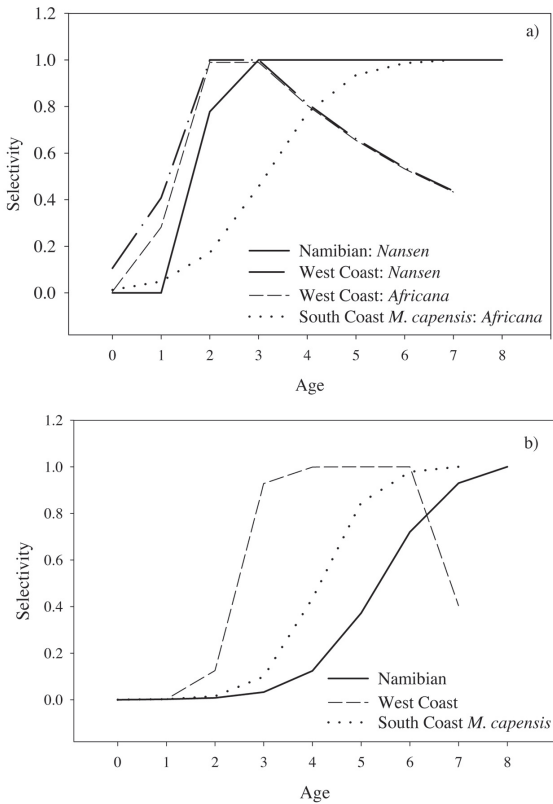


Figure 18. Current selectivity functions for (A) research surveys and (B) offshore commercial trawlers.

as relative indices in fitting the ASPMs, which consequently estimate a “catchability coefficient” q (effectively a multiplicative bias) for these surveys for each vessel and area. The results, together with bootstrap estimates of 90% confidence intervals for these biases, are shown in Figure 20.

Once again the surprising result is how different these estimated biases are between areas. It is, of course, possible that these differences are artifacts of mis-estimation of M or selectivity functions, perhaps related to biases in ageing. If they are real, however, one likely needs to look towards differences in substrates to explain these results. A q estimate well in excess of 1 suggests that there may be considerable underestimation of the sustainable yield of which the South Coast *M. capensis* resource is capable. Alternatively, however, the explanation may be that a large portion of the South Coast region is untrawlable, and hake densities in such habitats may be lower than in the trawlable areas sampled by the research surveys (the swept-area methodology assumes these densities to be equal; R. Leslie, MCM South Africa, pers. comm.). Although the estimates of q for the R/V AFRICANA and R/V NANSEN on the West Coast do not differ greatly, the direction of the difference is as would be expected from likely greater escapement of fish underneath the R/V NANSEN’s net (R. Leslie, MCM South Africa, pers. comm.).

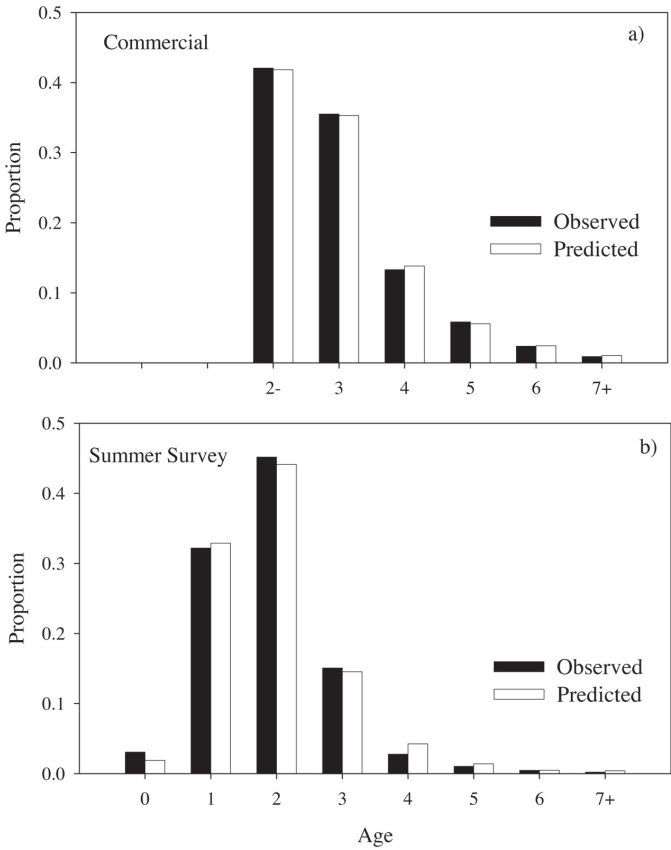


Figure 19. Fits to (A) commercial (1978–1999) and (B) survey (1985–1999) averaged catch-at-age proportions for West Coast hake.

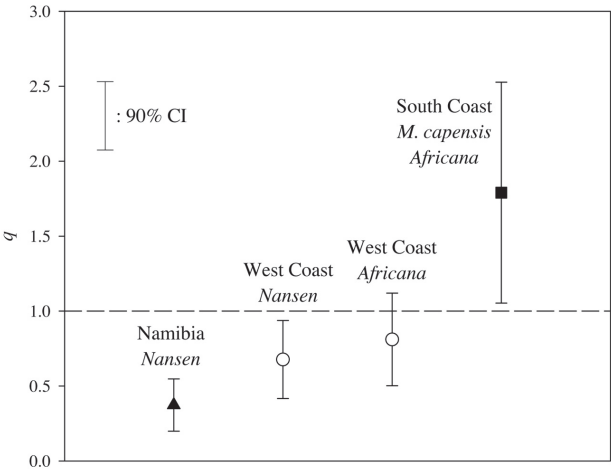


Figure 20. Swept area survey “catchability” (multiplicative bias) coefficients q (with respect to the most highly selected age group).

RECENT AND PRESENT (2001) BASIS FOR MANAGEMENT

OPERATIONAL MANAGEMENT PROCEDURES.—Over a little more than a decade now in South Africa, and for the last 5 yrs in Namibia, the primary basis for scientific recommendations for TAC levels for the hake fisheries has been the OMP approach (e.g., Butterworth and Punt, 1999; Cooke, 1999; Geromont et al., 1999).

This approach relies on using pre-specified data input to a pre-selected formula to compute TAC recommendations over a period of years—typically 3–5 yrs—until the process of selecting the formula is revisited. This selection process involves simulated forward projections of resource abundance for some 10–20 yrs under proposed candidate formulae (OMPs). The choice of a particular formula depends on its ability to best achieve a desired trade off between the conflicting objectives of higher catches on average, lower inter-annual TAC variability, and lower risks of unintended resource depletion. An important component of the approach, consistent with application of a precautionary approach given scientific uncertainties, is to check that candidate OMPs demonstrate robust achievement of objectives given possible errors in data, assumed population model structure, or implementation (e.g., actual catches differing from those recommended).

The motivation for such an approach to TAC recommendation, in contrast to the more traditional process of linking a harvest control rule to an annual “best assessment” was essentially three-fold: (1) to reduce resources expended on annual debates (of little real import) as to exactly what constituted the “best” assessment (for example by industry trying to obtain a slightly larger TAC) by applying a pre-agreed formula, (2) to concentrate research resources on more fundamental issues of greater import to optimal utilization of the hake population in the longer term, and (3) to better account for uncertainties, since in the context of management decisions for a longer-lived species such as hake, risk cannot be effectively assessed for a single decision for 1 yr, but only for a process of the continued application of some TAC-setting formula over time.

The process of prior agreement has the further advantages of creating an opportunity for stakeholder contributions, particularly regarding longer-term objectives and tradeoffs, and of planning for utilization stability without compromising stock conservation.

SOUTH AFRICA.—Over the period 1990–1995, TAC recommendations for both West and South Coast hake (for both species combined) were provided by an OMP based on the dynamic Schaefer model in combination with a $f_{0.2}$ harvesting strategy (Punt, 1991, 1992; see Fig. 21 for a graphical explanation of a $f_{0.2}$ harvesting strategy). Note that actually the TAC implemented is for both coasts together, based on adding the recommendations for each coast separately, with industry requested to operate to achieve roughly the split between coasts indicated by the separate analyses. The pertinent equations were:

$$B_{y+1} = B_y + rB_y \left(1 - B_y/K\right) - C_y$$

$$CPUE = q \left[\left(B_y + B_{y+1} \right) / 2 \right] e^{\epsilon_y}$$

$$TAC_y = 0.8 \left(\hat{r}/2 \right) \left(\hat{B}_y + \hat{B}_{y+1} \right) / 2$$

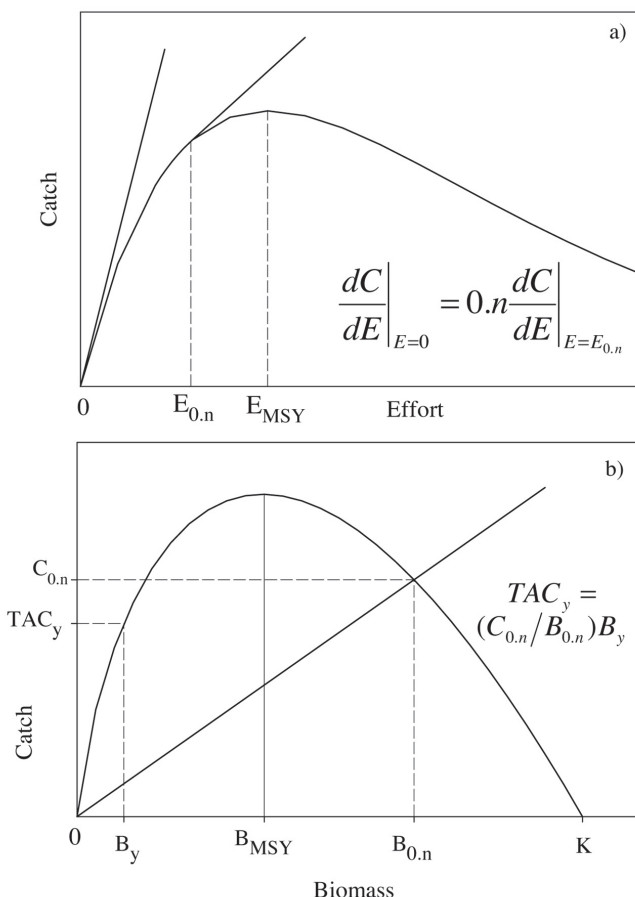


Figure 21. A graphical explanation of the $f_{0,n}$ harvesting strategy: (A) shows how the effort level $E_{0,n}$ is obtained from a sustainable catch vs fishing effort curve; this effort level corresponds to an equilibrium biomass $B_{0,n}$, and (B) shows how the sustainable catch vs. biomass plot is used to convert this information into a TAC recommendation. The following relationships hold for the Fox surplus production model:

$f_{0,n}$	$E_{0,n}/E_{MSY}$	$B_{0,n}/K$
f_{MSY}	1	0.37
$f_{0,1}$	0.78	0.46
$f_{0,2}$	0.63	0.54
$f_{0,3}$	0.50	0.60

where an observation error estimator (which assumed $B = K$ when exploitation commenced) was used to estimate model parameters (r , q , and K) and the biomass time series from input information comprising catch, CPUE, and survey abundance estimate series. It may seem strange that no account appears to be taken of catch-at-age information in the approach of equations (6). This perception would not be correct, however, because although the eventual OMP selected involved an age-aggregated model, the population dynamics model used for simulation testing of alternative

candidate OMPs did involve age-structure, the parameterization of which took account of catch-at-age data.

OMP candidates which used catch-at-age information (e.g., based upon Virtual Population Analysis, VPA) were considered in the selection process, but it was found that this led to greater inter-annual variability in catches with no compensatory gains in terms of either increased average catch or decreased risk (Punt, 1993). In other words, the VPA-based OMPs had a greater tendency to track noise in the data instead of only the abundance trends.

However, during the mid-1990s, problems started to arise with the continuation of this basis for TAC recommendations. On the West Coast, the resource recovery rate (in terms of CPUE) was proving to be less than had been predicted earlier (though the OMP had responded in the adaptive manner that its design intended, by increasing TACs more slowly than anticipated), and there was increasing systematic deviation between the CPUE data and the trend predicted by the dynamic Schaefer model of equation (6). Furthermore, concerns arose over the outcome of the CPUE GLM-standardization exercise as discussed above (see Fig. 9), with the result that the TAC was frozen at its then current level over 1996–1997, pending a process of revision of the OMP.

OMP REVISION FOR THE WEST COAST HAKE.—This revision process concentrated first on the West Coast, where the problems appeared greater. To account for the phasing out of net liners in an age-aggregated model, the CPUE series from the late 1970s onwards was split into two pieces, which were treated as non-comparable. Furthermore, the Fox model was found to perform better than the Schaefer model in tests of OMP candidates, so that the first of equations (6) was replaced by:

$$B_{y+1} = B_y + rB_y \left(1 - \ln B_y / \ln K\right) - C_y \quad (7)$$

In addition, to better moderate inter-annual TAC variations, the TAC formula was amended to:

$$TAC_{y+1} = \Delta TAC_y + (1 - \Delta) TAC_y (Fox, f_{0,n}) \quad (8)$$

where $TAC_y(Fox, f_{0,n})$ is the TAC, which would result under the combination of the Fox model and an $f_{0,n}$ harvesting strategy. The value of Δ was set at 0.5, and that of n in the $f_{0,n}$ left for decision makers as the control parameter for their tradeoff choice.

The three broad objectives identified as a framework for that tradeoff decision were: that in the 10 yrs following 1998 there should be: (1) a high probability of spawning biomass recovering to MSYL, (2) a low probability that spawning biomass might decline, and (3) a low probability of a TAC reduction early in this 10 yr period.

Three candidate OMPs were offered to decision makers, corresponding to the $f_{0.05}$, $f_{0.1}$ and $f_{0.15}$ harvesting strategies. Figure 22 shows TAC and spawning biomass projections at that time, with 90% probability intervals, under the $f_{0.1}$ option, while Figure 23 compares median projections for the three candidates. Note that $f_{0.15}$ offered the greatest extent of recovery, but also the greatest chance of a TAC reduction in the short term. The decision-makers eventual choice was for an $f_{0.075}$ option, and this

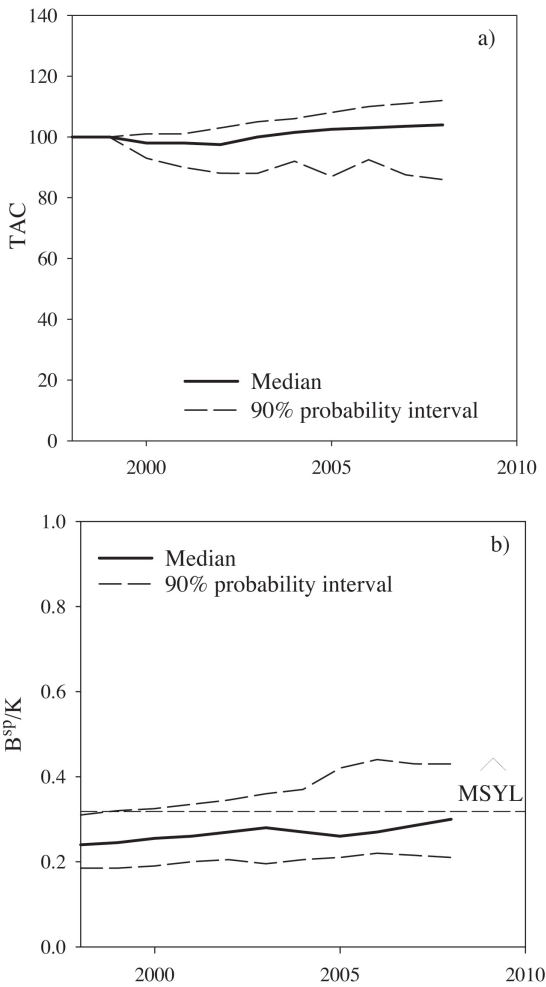


Figure 22. Projections for (A) catch and (B) depletion (B^{sp}/K) under an $f_{0.1}$ OMP for West Coast hake.

has been implemented from the 1998 season onwards (Anonymous, 1998; Geromont and Glazer, 1998).

Although the projections shown in Figures 22 and 23 corresponded to the assessed “best” model/assumptions for West Coast hake at that time, it is important to stress that the performance of the candidate OMPs was also checked for robustness in circumstances where certain of these assumptions might have been incorrect. For such tests, the model of the true underlying dynamics was changed to reflect: (1) different levels of recruitment variability; (2) bias in CPUE as an index of abundance; (3) absence of future surveys; (4) regime shifts (reflected by a changing value of the underlying K) (5) different natural mortality schedules; and (6) allowance for discarding. [Tests of the consequences of misplacement of the boundary between the West and South Coast stocks had previously been carried out by Punt et al. (1995).]

These tests suggested that performance was reasonably robust to these uncertainties, except for the combination of positive bias in future CPUE coupled to an

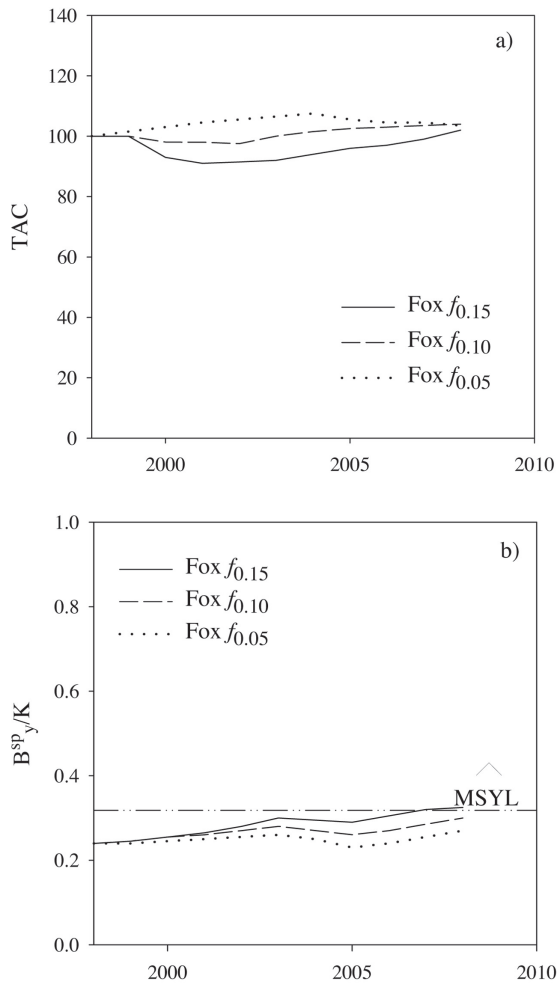


Figure 23. Median projections for (A) catch and (B) depletion (B^{sp}/K) for three $f_{0,n}$ OMPs for West Coast hake.

absence of surveys, which could result in a reduction in abundance. As fate would have it, mechanical problems with the R/V AFRICANA have resulted in a temporary suspension of its research surveys over recent years; the Norwegian R/V NANSEN has fortunately been available to fill the gap (see Fig. 5D), though this has not been an entirely straightforward process, as relative catchability calibration between the two vessels has had to be achieved within the assessment model (see Fig. 5 caption and Fig. 20).

OMP REVISION FOR THE SOUTH COAST *M. CAPENSIS*.—The South Coast hake OMP revision was targeted first at the *M. capensis* component of the resource only. The justification for combining the two hake species in previous assessments and OMPs had been based on simulations by Punt (1993), which indicated that it was safe to treat the two species as one for management purposes, provided the fishing selectivity pattern remained unchanged. However the introduction of longlining for hake

in the mid-1990s saw this fishery concentrating on older *M. capensis* on the South Coast, so it was considered necessary to develop an OMP for this species alone.

The assessment and OMP simulation trials were faced with the difficulty of the absence of a species-breakdown of the commercial catch. This was inferred by linking the depth distribution data for commercial catches (available from 1978) to the species proportion by depth estimated from the research survey information.

The primary objective for this OMP was to maintain the CPUE at its current level for reasons of economic viability, even though this was estimated to correspond to an abundance well above MSYL. Decision makers were presented with three options of the same form of OMP as adopted for the West Coast (i.e., based upon the dynamic Fox production model). Figure 24 shows median TAC and spawning biomass (roughly proportional to expected CPUE) projections for $f_{0.25}$, $f_{0.3}$ and $f_{0.35}$ harvesting strategies. The decision makers opted for $f_{0.3}$, and this has been used to recommend the South Coast *M. capensis* contribution to the overall hake TAC since 2000 (Anon. 2000; Geromont and Glazer, 2000).

NAMIBIA.—Over the immediate post-independence period, from 1991–1997, a simple basis was used to guide hake TAC recommendations. Swept-area-based biomass estimates were provided by surveys carried out by the R/V NANSEN, and the recommended TAC was set in the neighborhood of 20% of the component of this absolute estimate that corresponded to “fishable” hake of lengths in excess of 35 cm. By 1997, the TAC had risen to 120,000 t.

However, considerable controversy developed in 1997, in circumstances where both surveys and commercial CPUE had shown a decline of some 50% over the previous 3 yrs. On the one side, the Ministry’s scientists, who considered the R/V NANSEN abundance estimates to be reliable in absolute terms, argued for the TAC to be halved—an action that would have had severe repercussions on the nation’s economy. On the other side, scientific consultants for the industry argued that the R/V NANSEN results should be treated as relative indices of abundance only, and that very recent lower values were simply reflective of environmentally induced fluctuations in hake catchability. Their assessments on this basis indicated the resource to be well above MSYL, and they argued that the TAC could be doubled. Figure 25 shows ASPM assessments of the age 2+ biomass at that time; the very different results obtained depending on whether the survey results were treated as absolute or relative indices of abundance is clear.

This impasse was resolved by the adoption of a simple Interim Management Procedure (IMP), for which the formulae to provide the TAC recommendation (in thousand tons) were as follows:

$$TAC_{1998} = 150 \left[1 + 3 \left(s_{1998}^{CPUE} + s_{1998}^{survey} \right) / 2 \right]$$

$$TAC_y = TAC_{y-1} \left[1 + 3 \left(s_y^{CPUE} + s_y^{survey} \right) / 2 \right] \quad (9)$$

where s is the annual proportional change in the trend of the index over the previous 5 yrs. The underlying rationale was that if the resource status was depressed, surveys and CPUE would continue to decline (s negative) and the TAC would be reduced over time. However, if more optimistic appraisals were correct and recent trends in indi-

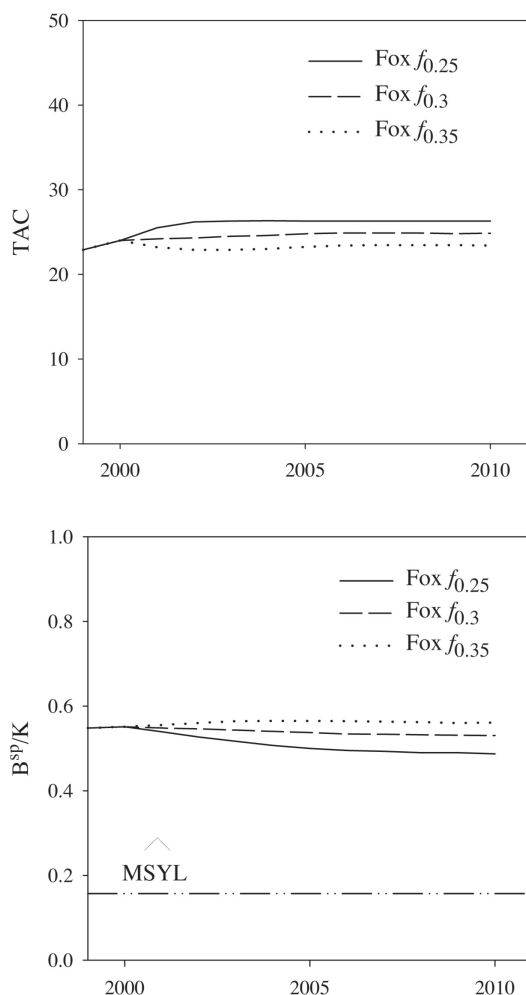


Figure 24. Median projections for (A) catch and (B) depletion (B^{sp}/K) under three $f_{0,n}$ OMPs for South Coast *M. capensis*.

ces merely a reflection of a short-term downward fluctuation in catchability, s would increase over time, leading to a TAC increase.

The control parameters of equations (8) (150 and 3) were chosen on the basis of simulation tests of different possible values for these parameters (Butterworth and Geromont, 2001). The choice was intended to achieve an appropriate tradeoff between: (1) sufficiently rapid TAC reduction to prevent undue further deterioration in the stock, if future abundance index trends indicated the more pessimistic appraisals of the resource to be correct; and (2) reasonable increases in the TAC over time if such future data supported the more optimistic appraisals.

This IMP was used to guide Namibian hake TAC recommendations for the following 3 yrs. Broadly speaking, both CPUE and survey results showed increases after 1997, and by 2000 the TAC had been increased to 194,000 t (Butterworth and Geromont, 2001).

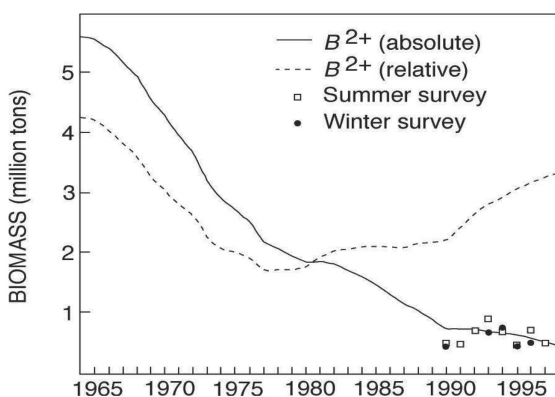


Figure 25. Competing Namibian hake assessments in 1997 (see text for details).

PLANS FOR MANAGEMENT IN THE IMMEDIATE FUTURE

SOUTH AFRICA.—In 2001, the West Coast component of the overall hake TAC was set using the combined species OMP adopted in 1998, and the South Coast *M. capensis* component by the OMP adopted 2 yrs later. The South Coast *M. paradoxus* component was computed as an ad hoc proportional addition to the West Coast OMP output, where this proportion was based upon the average ratio of the catches from these two components of the overall resource for the preceding 5 yrs.

From 2001, it was planned to move over the next 2–3 yrs towards three species-based OMPs, for *M. capensis* on the West Coast, for *M. capensis* on the South Coast (as in 2001), and for *M. paradoxus* for both coasts combined. This last combination is because of indications that the *M. paradoxus* resource behaves as a single stock across the present West/South Coast boundary.

The main reason for this planned change was the growing longline component of the fishery, with its different selectivity by species, age, and sex compared to trawling. For example, longlining takes essentially only 6+ aged hake, compared to the typical age 3+ for trawling. The primary difficulty this introduces is how to effect species-splits of the historic catches in the absence of direct observations at the time.

NAMIBIA.—The Namibian hake IMP described above has passed its “sell-by” date (it was designed to be applied only for 2–3 yrs). Broad objectives are to replace this for the short-term with a combined species OMP, and later to move towards separate OMPs for the two species, perhaps also making allowance for migration of hake across the border with South Africa.

More specific objectives for the first of these exercises are for the combination of a low level of inter-annual TAC variability, and a capability for adaptive response given the wide range of scenarios that could describe the true status of this resource. To illustrate this, three scenarios are identified here in the context of the associated prognoses for the industry: (1) “pessimistic”: the R/V NANSEN survey estimates are reliable in absolute terms ($q_{survey} = 1$); (2) “intermediate”: the present baseline assessment is correct (we use here the deterministic ASPM of Fig. 4A); and (3) “optimistic”: steepness h is set at the upper end of its 90% confidence interval estimate (i.e., $h = 0.37$ instead of the best estimate of $h = 0.28$).

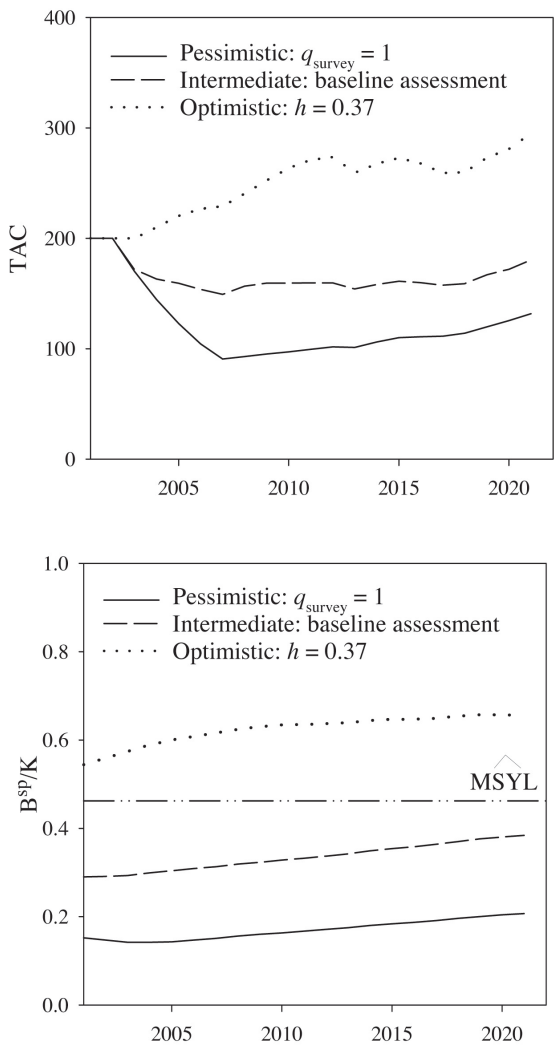


Figure 26. OMP robustness tests for Namibian hake: (A) catch and (B) depletion (B^{sp}/K) deterministic projections.

The most promising approach developed to date is an OMP based on an ASPM to which all past abundance and catch-at-age information, but only future CPUE and survey abundance data, are input. Future catch-at-age data were not considered for input because of uncertainty whether resources would be available to age catch samples on a regular basis. Natural mortality and selectivities are set at their baseline assessment best-estimate values, so that only the K^{sp} and h parameters of the ASPM are updated as more data become available. The catch control law which provides the TAC recommendation based upon this assessment constitutes a slight variant of that for an f_{MSY} harvesting strategy, which is adjusted to moderate interannual TAC changes.

Figure 26 illustrates the performance of this OMP for the three scenarios above for the simplest “deterministic” case; i.e., no noise in future abundance indices and no

future recruitment fluctuations. What is evident is that the OMP shows the adaptive behavior desired. If the optimistic scenario applies, the TAC is increased. However, if the intermediate or pessimistic scenarios reflect reality, the OMP reduces the TAC over the next 5 yrs to secure an increase in abundance towards the MSYL.

SUMMARY

Management can claim to have achieved sustainable management of the hake stocks off Namibia and South Africa over the last three decades, given that all have increased from their low levels of the early 1970s. However success has been limited regarding the objective of restoring these stocks at least to their MSYLs. Recoveries have been less rapid than predicted earlier, and the stocks have proved to be less productive than previously surmised.

Some key questions concerning the assessments of these resources remain: why are the estimates of recruitment variability so low, natural mortality so high, and steepness, selectivity, and the multiplicative biases for survey estimates of abundance so different for the different stocks? Possible bias in age readings might provide an explanation for some of these features of the assessments.

The OMP basis used to provide TAC recommendations for these resources over recent years has demonstrated its intended adaptive behavior in responding to new data forthcoming over time. The primary medium term objective is to move to a management approach which distinguishes the two species: *M. capensis* and *M. paradoxus*.

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